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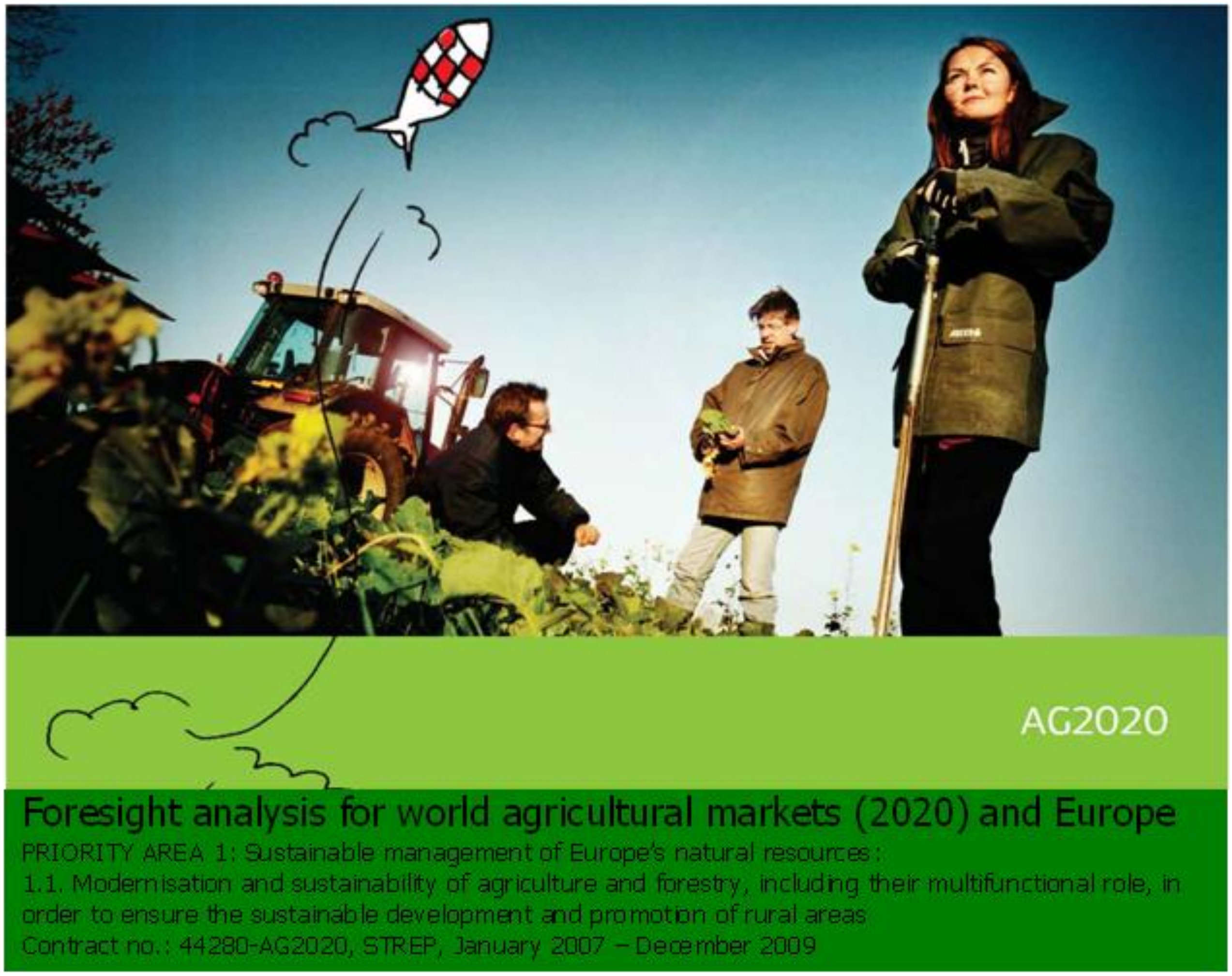

Future technological developments to fulfil AG2020 targets

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Contents

1. Introduction

This report constitute an analysis of selected technologies that are anticipated to underpin the images described in Giaoutzi et al (2008) and it proposes policy measures to promote these technologies. It builds on Borch et al (2008) where a more detailed description of technologies can be found.

Technology is a broad concept that deals with humans' usage and knowledge of tools and crafts, and how it affects their ability to control and adapt to the environment. One specific definition is that technology is the process by which human muscles are empowered with non-human energy (Hall et al1986). However, a strict definition is elusive; "technology" can refer to material objects of use to humanity, such as machines, hardware or utensils, but can also encompass broader themes, including systems, methods of organization, and techniques. Tools and machines need not be material; virtual technology, such as computer software and business methods, falls under this definition of technology. Technology can most broadly be defined as the entities, both material and immaterial, created by the application of mental and physical effort in order to achieve some value. It is a far-reaching term that may include simple tools, such as a wooden spoon, or more complex machines, such as a particle accelerator.

As in essence technological development is innovative forecasting specific technologies is difficult ; history has shown that the technologies that have had the most significant impact on the societies have not been foreseen. And when the technology was first developed often it has shown to change the societies in ways that were not foreseen even though the technology was known. The Internet is the classical example: it was not foreseen; it was developed for scientist to share data; when it was there it got a life of its own; and in a matter of decades it has completely changed the society. Another example could be the combustion engine, which combined with the supply of cheap oil completely has shaped the economy of the 20th century. But for AG2020's time frame (2020), important technologies are expected to already be known and more or less developed today but perhaps not fully implemented.

By the first definition above, a prerequisite for technology is energy. Therefore, we begin with a chapter on energy as driver for technological development. Then we elaborate on the part of narratives of the three AG2020 images focusing on technologies and the resulting imperatives for technological development.

Based on the technological narratives and imperatives, we select a set of present available technologies that are able to support the society in reaching the targets set up by AG2020. For each of these technologies, we evaluate the strengths and weaknesses of the technology to reach the target as well as the threats for development of the technology in the respective images. Finally policies for promoting and spreading technologies are proposed,

2. Energy as driver for technological development

"The scale and breadth of the energy challenge is enormous – far greater than many people realise. But it can and must be met. The recession[...] has made the task of transforming the energy sector easier by giving us an unprecedented, yet relatively narrow, window of opportunity to take action to concentrate investment on low-carbon technology" (IEA (International Energy Agency) and OECD 2009)

As exemplified by this quote from the developed world's primary energy advisor it seems unavoidable that energy constraints will be a major driving force for the development and implementation of technologies – within the energy producing sector as well as the energy consuming sectors.

From a biophysical perspective, economic activities can be divided into two main groups: (1) activities which produce a surplus of energy (energy net-producers), e.g., pre-industrialized agriculture, fossil fuel extraction and wind turbines and (2) activities which use more energy than they produce (energy net-consumers); basically all remaining economic activities e.g., research and development, industries, industrialized agriculture, etc. It is a physical fact, that the energy net-producers determine the potentials for energy net-consumers. When it comes to the labour market this relation can be summed using the classical division of labour market into three sectors: primary (resource extractions and energy production), secondary (manufacturing and processing) and tertiary (service and desk-jobs). The surplus of energy in the industrialized world, following the exploitation of fossil fuels, has allowed for increased automation in traditional labour intensive industries such as agriculture and manufacturing. This has implied a rapid increase in labour efficiency (productivity per labour hour) in primary and secondary sector. As a result, the tertiary sector has had a dramatic increase.

From a historical perspective the industrialized world is facing unprecedented challenges regarding energy supply and production. During the 19th and 20th century coal, oil and natural gas has been the society's main source of energy. By 2006 oil accounts for 34 %, coal for 26 % and natural gas for 20 % of the worlds primary energy mix (IEA (International Energy Agency) and OECD 2008). The impact and success of the fossil fuel has been astonishing, and can be explained by two important factors: (1) The energy return on energy invested ratio (EROI) of oil was up to 100 in the first half of the 20th century (Cleveland et al. 1984, 890-897) and (2) During the 20th century the access to oil has with few exceptions been unrestricted. The exceptions are the oil-crisis of the 1970'ies where oil prices were rising dramatically because of restricted oil exports from OPEC-countries, and the dramatic increase of oil prices during 2007-2008 indicating that oil demand for some reason was restricted by limited oil supply. Besides these instances, the oil prices has been rather low and stable since the Second World War indicating that access to oil has been more or less unrestricted.

The question is if fossil fuel can still be as good a source by 2020 and beyond; it is becoming increasingly difficult (expensive in terms of both energy and money) to extract oil, and consumption of fossil fuel is very likely to be political regulated due to climate change. IEA is warning about severe risk of an *oil supply crunch before 2015* (IEA (International Energy Agency) and OECD 2008) and according to independent researchers a global peak in oil production resulting in a continues decline in oil production is very likely to be very near or even passed in 2008 (Jakobsson et al. 2009), and under all circumstances consensus is growing that it will happen before 2020. A similar conclusion is also made in a recent very thorough report prepared by the UK Energy Research Centre (UKERC 2009). Ultimately, alternative power sources have to be developed because fossil fuel is a limited resource. Developing an economy that by 2020 still is depending on fossil fuels will only make problems worse in case of supply disruptions.

Much attention has been paid to biofuels as a renewable energy source that can substitute fossil fuels. But in general biomass is far from being as good a source of energy as fossil fuel, because a lot of energy and human labour needs to be invested in producing the biomass and in processing the fuels. Compared to fossil fuel, biobased fuels involve production and concentration of biomass and processing into fuel; fossil fuels are already there in concentrated form, and thus they should only be extracted and refined.

As an example several studies shows that corn ethanol, which is the most widespread bioenergy technology in USA, yields between 1.1 and 1.5 times the energy that is used in the process (Giampietro and Mayumi 2009,Farrell 2006). This means that if the ethanol production is operating at 1.3:1 output/input of energy carriers, then there should be produced 4 litres of ethanol to supply one litre to the society.

To put these numbers in perspective Giampietro and Mayumi (2009) argues that any process with a output/input ratio of energy carriers below 5:1 has little potential of becoming a useful primary energy source for an industrialized economy, since too much human labor and energy would otherwise needed to be allocated to energy production. To r this ratio the corn ethanol process would have to become nearly four times as efficient; either input of energy carriers should be reduced to 25 % or output of energy carriers should be four times higher.

On top of this comes the dilemma with limited land, water and nutrients. According to Johansson et al (2010) the current food produced in EU27 is not even enough to cover demand and imports are required. So trying to replace the dependency of foreign oil with homemade biofuels in EU would - other things being equal - imply that EU would become increasingly dependent on imported food. In all cases biofuels has a very limited potential to replace fossil fuels as a main power source for an industrialized economy.

Finally it should also be mentioned that there are substantial challenges with producing sufficient amount of biomass in a sustainable way. One of these is to bring the nutrients back to the agro-ecosystems to maintain the soil fertility (see e.g. Østergård et al (2010)). Today soil fertility in conventional agriculture is in general maintained on a year to year basis by application of commercial fertilizers (NPK). Two central problems are facing the future supply of commercial fertilizers: Phosphorus (P) is mined as a mineral, and the production of P is foreseen to peak within few decades because of depleted resources (Cordell et al 2009). Future agriculture should be able to produce P in alternative methods: either by extracting P from the oceans where the used P is ultimately deposited or by recycling P within the society. The first option seems unlikely from a thermodynamic point of view since the enormous amounts of energy should be used for concentrating P from very weak dilutions in the oceans. The second option would imply closing the circle of nutrients in a way that P is collected from the households and waste water and brought back to the agricultural fields. Today, N is produced from the air using natural gas in a Haber-Bosch process and this process is expensive in energy. As an example, the European fertilizer Manufacturers Association calculates that fertiliser production, transportation and application in 2000-2001 accounted for about 50% of the direct and indirect energy consumption in wheat production in EU (European Fertilizer Manufacturers Association 2008). In contrast to P, N can be fixed from the atmosphere by growing legumes in the crop-rotation. The cost of this method is an overall lower output since part of the land will need to be used for maintaining soil fertility.

Other renewable energy sources that can yield more energy in terms of absolute amounts and relative to that invested in producing the energy thus has to be developed in order to provide enough energy to power the rest of the economy. The potentials of sun, wind, geothermal and water based energy are large, but a general problem with these alternative energy sources is that they are producing electricity and not liquid fuels, that can be used in the existing transportation system (regarding both infrastructure and machinery).

Finally nuclear energy and coal to liquid (CTL) should also be considered as options for producing sufficient energy. But it is doubtful whether such facilities can be planed and built within the timeframe of AG2020, and there are still unsolved and overwhelming problems with handling nuclear waste and CO_2-emissions, respectively.

3. Role of technologies in AG2020 images

The role of technology is different in the three images; even if some technologies are important in all images they might be used differently. Below we describe these principal differences by the use of narratives and imperatives for technology based on the Giaoutzi et al (2008).

3.1 Image I

Technology imperative: *Technology should support mass production, specialized regions and globalization.*

Technology narrative: *Don't hinder technological progress; Technology gives the solution to our problems!*

Across EU, regions are prospering from increased specialization in different branches of high-tech industries and agricultural production. The specialization of the labour force and the production means that the transportation of goods and people has increased steadily, which has lead to a development of the European highway and high speed train networks. At the same time more people employed in knowledge intensive jobs are doing some of the work from home-offices supported by the Internet. Global specialization has likewise increased and EU is importing both material goods from all over the world.

The increased specialization of agricultural production into bigger units of and large slaughterhouses has lead to development of new systems to track the food and feed such as RFID-tags. Pigs are increasingly produced in pig cities, which is a combination of a greenhouse horticulture and stable system, with plants benefiting from the heat produced by the pigs, and recycling some of the nutrients on location.

The labour force is in average highly educated. This is a must to meet the need in high-tech sectors as well as in agriculture and other production and processing industries, where advanced machines and robotics are widespread.

The blending targets for biofuels are complied with by means of energy crops and industrial-scale bio-refineries. The increased need to transport and increased use of machineries means that even though new technologies are more energy-efficient the absolute energy use has been rising, making it necessary to import biofuels from non-EU regions to meet the targets.

Relying largely on fossil fuel, heavily investments in CCS has been necessary to comply with the target for GHG-emission. Also an enlargement of nuclear electricity generation capacity is started and facilities for producing liquid fuels from coal is planned.

In this image the overall criteria for success is economic growth thus following the projection from the post world war period. Problems (environmental, social or economic) are solved by investing in research and development. Technologies that support regional specialization and thus inter-regional trade are "good". This also implies that technologies that can reduce labour in the primary and the secondary sector by increased automation and thus increase the amount of people working with innovations and service jobs in the tertiary sector are good. The costs of these kinds of technologies are that more energy for doing mechanical work and energy for transporting goods and people are needed.

3.2 Image II

Technology imperative: *Sciences and technology should support development of a biobased economy; that is, development of biobased alternatives to fossil fuels, chemicals and materials.*

Technology narrative: *Industrialized bio based economy is the way ahead*

in this image the international specialization of labor is medium. Agriculture regains importance for the development of rural regions due to the increasing production of renewable resources, e.g. biofuels, and rural development is supported by appropriate policy measures. There is a high mandatory blending target of biofuels, with special emphasis on the 2nd generation of biofuels. ICTs play an important role in everyday life and facilitate mobility. It also contributes to the quality in production, communication and mobility. The agri-food sector is exhibiting a continuous trend in technological cost-saving progress, traceability and monitored labelling.

The labour force is in average highly educated. This is a must to meet the need in high-tech sectors as well as in agriculture and other production and processing industries, where advanced machines and robotics are widespread.

Demand for food and water is high. This together with sustained high prices for energy has put focus on agriculture as an area for action. There is an enhanced use of biotechnology, especially those that increase yield and tolerance to drought together with biofuels. Biorefineries are a possible solution in many parts of EU.

There is a medium focus on food quality, expected throughout the whole range of preferred food products (regional, international food) and a strong belief in labelling. Green values are widespread with both local and international lifestyles, while food preferences appear to be mixed, ranging from local to international.

3.3 Image III

Technology imperative: *Technology should support organic and low-input agriculture and production and consumption of local quality products.*

Technology narrative: *Don't cross natural boundaries by technology - Exploit natural processes!*

The economy is characterized by local production and consumption. People prefer to buy locally produced and processed food as we know it from the contemporary slow food movement. This means that the economy of scale that is achieved in today's industrialized food production system is not achieved in this image. As a result more people are needed in both farming and in processing of food, to produce the high quality products that are in demand.

The re-localization of production and consumption is supported by a green tax reform, where taxes are shifted from labour to energy and resources. This strengthens the incentive to recycle resources locally and to use labour intensive production processes that are saving energy and resources. Problems are addressed on a local scale, and local investments are directed in low-tech bio-energy and biomaterials.

Societies are now organized in smaller units increasing the number of different functions that is accessible by food and by-cycles. Cities are supplied with food and energy from the region and form urban farming. Big cities are having severe difficulties with providing the needed food and energy.

The society emphasizes on thinking in cycles rather than in linear chains, on transparency and cooperation in agricultural production improved by nearness and evaluating new technologies from a precautionary principle.

4. AG2020 targets and technological answers

The main criterion for the technologies included in this report is whether they can be expected to support the agri-food sector in reaching the targets defined in AG2020. The targets are listed below accompanied with a short description of the parameters that technologies are expected to have an impact on. For a more elaborate description of the targets see Giaoutzi et al (2008).

Target 1: GHG emissions - Decrease of N_2O and CH_4

Primarily, human-related sources of N_2O and CH_4-emission are agricultural soil management and animal manure management. Emissions of N_2O may be reduced by a number of agricultural practices and activities, including reducing the use of synthetic and organic fertilizers and reducing the direct application of livestock manure to croplands. Important technologies for reducing the emissions are within crop and animal management (e.g. robotics for precision farming), plant breeding (e.g. providing varieties with high nutrient uptake efficiency and fodder with high nutritional value), animal breeding (e.g. animals with high nutrient uptake efficiency) and biogasification (producing biogas from manure and using the effluent for fertilizer). Another kind of solutions is to produce more food in closed artificial growth systems where all inputs are industrial produced and all emissions are controlled.

Target 2: Biodiversity - Halting the loss of biodiversity by 2020 – High rate of halting

Loss of biodiversity is related to destruction or degradation of natural habitats. Primary causes are changes in land-use and eutrophication of terrestrial and aquatic habitats. Technological solutions to eutrophication are similar to the technologies discussed for Target 1.

Two different approaches to preserving habitats can be foreseen; either by making agricultural land more diverse with for example smaller fields divided by hedge rows, increased use of agro-forestry and intercropping and by limiting use of pesticides and fertilizers. Or by dedicating part of the land to organic or low-input agriculture or nature preserves and then have intensive high input agriculture on other parts. These approaches do not in themselves point to specific technologies, but different technologies are likely to support either low or high input agriculture.

Target 3: Competitiveness/efficiency - Strong competitiveness /efficiency in the agri-food sector
Competetiveness can be ensured by decreasing need for human labour and/or industrial input to agriculture, or increasing output from agriculture. This requirement does not in itself point to specific technologies, but to a range of different ways of producing agricultural products more cost efficient by either saving money on inputs or generating higher outputs. Infrastructure (e.g. ICT and transportation)

Target 4: Multifunctionality - Multifunctionality of rural regions – high level
Multifunctionality is a way of making explicit the ways that agriculture creates value for society, besides engaging in global competition to produce commodities for the lowest prices and in the most competitive way possible. Agriculture for example facilitates ecosystem services such as climate regulation, water regulation, soil formation, nutrient cycling, waste treatment, pollination, biological control and preservation of genetic resources in addition to food and feed production. The capacity of an agro-ecosystem to deliver these services is, however, seldom credited on the global marked.

Some rural regions have started to consider multifunctionality of non-agricultural activities by looking at activities such as energy production, small scale industry and specialized production.

Multifunctionality, based on diversification of rural activities (inside and outside agriculture), is necessary for growth, employment and sustainable development in rural areas. Tourism, crafts and the provision of rural amenities are growth sectors in many regions and offer opportunities for both on-farm diversification and the development of micro-businesses in the broader rural economy.

Target 5: Food and feed traceability - Food and feed traceability – High rate,
In centralized and industrialized food production and processing, traceability is important because a contaminated batch of food or feed can be spread to a huge area and to thousands of costumers.

Food and feed traceability can be improved by adding metadata to agricultural products describing the origins of the product. The technologies for labelling may in the future be based on nanotechnologies like RFID tags.

Target 6: Biobased economy - Blending targets in 2020: transportation fuel 10%, electricity 7% and chemicals 10%.
The economy cannot rely on fossil fuels forever. Technologies that can substitute oil, gas and coal as energy and materials are needed. A key challenge in meeting the targets is to produce enough biomass of various kinds and get access to waste biomass for bioprocessing; a challenge that may turn out to be impossible. Biomass produced for energy and material purposes may require other characteristics than biomass for food and feed. Again this requires plant breeding aiming at plant material providing these characteristics, e.g. a larger green biomass compared to grain biomass. The technologies needed for reaching this target is thus both concerning biomass production and the specific bioenergy and refining processes.

Technologies that can help compliance with the AG2020 targets have been identified in a previous report (Borch et al 2008), and the gross list has been discussed and modified in the AG2020 Chania workshop September 2009 with participation of experts from the industries. Table 1 shows the result of this process.

Table 1: AG2020 Targets and associated technologies

Target	Technologies in relation to agriculture to support target
1	• Soil, crop and animal management (e.g. smart crop rotation, cultivation and soil preparation technology and precision farming) • Plant and animal breeding (e.g. genetically modification and breeding technologies using DNA markers) • Biogas production (e.g. fermentation technologies) • Synthetic biology (produce food in closed systems)
2	• Soil, crop and animal management (e.g. crop rotation, cultivation and soil preparation technology and precision farming) • Plant and animal breeding (e.g. genetically modification and breeding technologies using DNA markers)
3	• Any technology that decreases need for human labour and/or industrial input or increases output • Infrastructure (e.g. ICT and transportation)
4	• Infrastructure (e.g. ICT and transportation) • Soil, crop and animal management (e.g. crop rotation, cultivation and soil preparation technology and precision farming)
5	• Traceability technologies (e.g. Radio Frequency Identification (RFID tags))
6	• Plant breeding (e.g. breeding technologies using DNA markers, genetically modification) • Bioenergy (e.g. biogas, bioethanol, CHP) and biorefineries

5. Examples of future technologies

In this chapter, examples of technologies from Table 1 are elaborated on in terms of *strengths* and *weaknesses* as related to the AG2020 targets, and it is discussed if and how they can be *applied* in the images. Potential *threats* for implementation of the technology are identified, and are later used to derive relevant policies presented in chapter 6.

5.1 Soil, crop and animal management

5.1.1 Crop rotation, cultivation and soil management technology

Whether this can be characterized as a technology can be discussed. However developing new and spreading already existing growing systems with for example reduced or no tillage, catch crops and smart crop rotations has a big potential. Usage of biological and agricultural knowledge, also called 'good agricultural management', can be an efficient way of minimising the environmental effect of farming.

The physical and chemical structure of the soil as well as its biological activity are fundamental to sustaining agricultural productivity and determine, in their complexity, soil fertility. Management also seeks to enhance the biological activity of the soil and protect surrounding natural vegetation and wildlife.

Strengths

- Reduction of nutrient leaching and runoff by closing the loop holes in the nutrient circulation with catch crops *(Target 1 and 2)*
- Improvement of soil fertility by minimizing losses of soil, nutrients, and agrochemicals through erosion, runoff and leaching *(Target 1 and 2)*
- Reduction of soil preparation and thus machinery and energy usage *(Target 6)*

Weaknesses

- Uncertainty regarding reduced or no tillage effects on weed control

Applicability related to images

This technology or approach is relevant to all three images.

Threats

- Relatively cheap commercial fertilizers (NPK) and fuel makes it unnecessary for the individual farmer to worry about loss of nutrients and unnecessary soil preparation
- Local knowledge on soil condition can easily be lost in mergers of farms, or transfer of ownership if a record of the inputs and outputs of each land management unit is not maintained
- Access to knowledge on the latest growth principles require access to consultative service or databases through broadband
- Farmers may be reluctant to accept new principles of organising and operational planning

5.1.2 Precision farming

In precision farming, IT, sensors, GPS and robots can be utilised in order to adjust the production of raw material (plants and animals) to conditions in the specific area or to specific animal or plant needs for nutrients or care. Examples of precision farming are: Weeding robots, precision sowing in patterns that improve crop competitiveness, precisely placed slurry that improve uptake and crop growth and milk robots and surveillance systems that allow free-range animals. Precision farming can thus be seen as a supporting technology for cultivation and soil preparation as discussed above.

Strength

- Reduction of the use and thus leaching of fertiliser and pesticides *(Target 1, 2)*
- Improvement of resource efficiency in both crop and animal production *(Target 1, 2)*
- Reduction of the use of labour in farming phase *(Target 3)*

Weakness

- Depending on the economic situation of the region a reduced need for labor in agriculture can be seen as a weakness for the development of rural areas *(Target 4)*

Applicability related to images

The technology is relevant for all images. However, in image III agriculture is more likely to be low-input and more labor intensive. Expensive technology can be out of reach for many farmers.

Threats

- Robotics is likely to be expensive to invest in and to maintain. With the current economic instability and the tight economy of many European farmers it is doubtful if farmers and banks are willing to invest heavily in new machinery not yet proven to be economically sound
- While robotics is well matured for industry purpose application for agriculture is still lacking behind and software that can interpret the sensor-data and measure the allocation of pesticides and fertilisers are yet to be developed

(General literature sources: Borch 2007; Cuhls 2006; FAO 2009; Østergård et al 2009, Thoni et al 2009)

5.2 Plant and animal breeding and gene technologies

Breeding is the way to change the genetic material of crops and livestock and is divided into three processes: identifying genetic variation, selecting individuals with desirable traits and making them reproduce. In traditional breeding, only natural genetic variation is applied whereas in molecular breeding variation is generated by genetic modification e.g. techniques that makes it possible to change genetic material in a way that does not occur in nature. These changes may occur by inserting desirable pieces of DNA into an organism, by altering the expression of already existing genes or by fusing living cells so new combinations of genetically material arise. The selection process uses mainly direct selection methods based on visible or measurable characteristics of the desirable traits. However, also marker assisted selection (MAS) based on neutral characteristics which with large probability coincide with specific expressions of traits of importance for the breeder is applied; their function is based on genetic linkage between the genes for the characteristics (markers) and the important traits. In connection with molecular breeding, DNA marker technology has been developed. It is important to notice that this technology does not involve genetic modification and can as such in principle be applied also in breeding programmes not allowing genetic modification (e.g. breeding for organic agriculture). The selection process may be performed by the breeder alone or may involve also end users of the products like millers, bakers and consumers. In this case, breeding is said to be based on participatory principles.

Technologies changing genetic information make it theoretically possible to develop organisms and new biological systems that require specifically designed artificial environments. This way of thinking has lead to the concept synthetic biology which refers to both: the design and fabrication of biological components and systems that do not already exist in the natural world and the re-design and fabrication of existing biological systems. Synthetic biology studies how to build artificial biological systems for engineering applications, using many of the same tools and experimental techniques as in systems biology. But the work is fundamentally an engineering application of biological science. The focus is often on ways of taking parts of natural biological systems, characterizing and simplifying them, and using them as a component of a highly unnatural, engineered, biological system.

Below is considered two breeding technologies and synthetic biology.

5.2.1 Genetic modification of crops (GM)

Strength:

- Development of new farming products with increased market value including crops that can be used both for fuel and fibre *(Target 3, 6)*
- Reduction of the nutrient loss by improving nutrient and water uptake *(Target 1, 2)*
- Optimization of feeding characteristics by removing, reducing or changing nutrient content in feed for domestic animals *(Target 1, 3)*
- Increased biological diversity in the field by development of insect resistant crops that reduces the need for pesticides *(Target 2)*
- Reduction of the need to apply herbicides by improvement of crops ability to compete with weeds *(Target 2)*
- Reduction of soil preparation by creation of herbicide tolerant crops

Weakness

- No guarantee that the expected traits will be fulfilled
- Development and testing of new GMOs are expensive and time consuming
- Difficult to develop quantitative traits influenced by the interaction of many genes like disease tolerance, general plant performance, yield, nutrient uptake efficiency, etc.
- Risks associated with releasing genetic modified plants in the environment are unknown
- Risk of generating resistant types of weed
- The introduction of GM soya and maize has so far not resulted in a greater rise in yield over time than the historic increase in yield achieved through traditional plant breeding

Applicability related to images

Only relevant for Image I and II. The technology will not be accepted in Image III due to its conflict with the basic principles of this image.

Threats

- Gene modification is controversial: Public hesitance towards the technology
- Lengthy authorization procedure makes it less attractive to invest in developing new GM crops

5.2.2 DNA marker assisted breeding of animals

Biotechnology has three main applications for livestock and poultry: breeding, propagation and health (diagnostic and therapeutic). DNA technologies are used in connection with marker-assisted selection of breeding animals. The largest commercial application of biotechnology in animal breeding is the use of marker-assisted selection (MAS) to improve the accuracy and speed of conventional breeding programs.

Strength

- Breeding based on DNA technology can speed up breeding programs significantly (target 3)
- Diagnostics can be used to identify serious inherited diseases and remove afflicted animals from breeding programs (target 3)

Weakness

- Many of these techniques for breeding and propagation are at present too expensive to be widely used for basic animal breeding. Its use is limited to the reproduction of high-value animals such as breeding bulls or boars
- Transfer from traditional to modern breeding systems is slow for meat production (and some extend dairy) due to long production cycles

Application related to images

Market-assisted selection is a technology with relevance for all images.

Threats

- Public hesitance towards GM-technology may affect application of MAS technologies even if they are not based on genetic modification.
- MAS-programs need international coordination and knowledge sharing order to be effective

5.2.3 Synthetic biology

Strength

- Construction of new biological parts, devices and systems, and the redesign of existing natural biological systems for useful purposes (Targets 1, 3, 6)

Weakness

- The potential is rather unknown but promising potential applications can be envisioned within areas such as energy, medicine and food production
- With regard to biosafety it is not clear how to assess the risks of introducing new synthetic organisms in the natural environment
- It is likely that it will become harder to monitor misuse of research and organisms, which pose a risk to humans and the environment.
- There is a fear that patents on biological building blocks may impede research and innovation due to a need to bring together widely spread patent rights when building synthetic organisms.

Applicability related to images

Only relevant for Image I and II. The technology will not be accepted in Image III due to its conflict with the basic principles of this image.

Threats

Ethical issues in relation to synthetic biology arise from its aim at synthesizing new life forms. It might very well turn out that it isn't the quantifiable risks of synthetic biology, which will generate public reluctance to the technology, but non-physical harms, e.g. that it challenges their concept of life.

(General literature sources: Lammerts van Bueren et al, 2010; http://syntheticbiology.org/; Runge and Ryan 2004; Danish Ministry of Food, Agriculture and Fisheries 2009; Cuhls 2006)

5.3 Information and communication technologies (ICT)

Information and communication technologies (ICT) have developed rapidly the last decades and are offering new opportunities in most sectors of the society. Regarding agriculture ICT has strong overlap with precision farming (discussed above) because it offers a technical platform for organizing e.g. site and animal specific data that in turn allows a more efficient management of crops and animals. ICT also makes it possible to instantly share and access data and information independent on spatial distribution via the Internet.

5.3.1 Internet access

Strengths

- Access to the internet (ICT) can contribute to rural development by creating new business opportunities such as tele-working, tourism *(Target 4)*
- ICT offers many possibilities for managing and trace the food chain from "stable to table" (elaborated below) *(Target 5)*
- Online and information systems for farmers can among others be used for efficient crop production, by providing weather data, on-line contact to agronomic advisors etc. *(Target 4)*

Weaknesses

- The Internet is in many aspects a robust system, but it-networks does involve a risk of braking down. A collapse can either be caused by technical failures and human errors (power supply can fail, satellites can malfunction and optical fibres can break), or be caused by hostile attacks from criminals or nations. Even though the chance of it happening is often perceived as minimal, then the consequences would still be devastating.
- It-networks involve a significant electricity use

Applicability related to images

Development of ICT-infrastructure is equally important in all images.

Threats:

- The cost of developing and maintaining high-speed access to the Internet in rural, less developed and low-populated areas can be too high
- Lack of education and experience with using computers and on-line services can in some rural areas be a problem

5.3.2 Traceability technologies – e.g. RFID-tags

RFID-tags are similar to barcodes (e.g. EAN-10), but as they identify products automatically and transfer information electronically without inter-visibility by means of radio signals, they are utilized increasingly in many supply chains.

Strengths

- Documentation of food and feed production history using RFID tags and sensors has the potential of facilitating whole chain traceability and thus support food safety, animal and plant health, and market development *(Target 3 and 5)*
- Production data can be used to establish quantitative models of bio-systems, decision support and management programs, which can be used by farmers and authorities to make better decisions *(Target 1 and 3)*

Weaknesses

- It is a big challenge to present data to consumers allowing them to make real choices based on profound information. Information overload may cause operators and consumers to ignore important information and in turn act suboptimal.
- The machine-man interface must be very user friendly taking into account the different levels of education among farmers and consumers across EU

Applicability related to images

Traceability is always important for food. But the need to organize and control information of origin is increasingly important for centralized processing due to health risk, making these technologies important to image I and II.

In Image III the production is more locally and thus the health risk associated with each batch is in general smaller. But in order to get a price premium for high quality local products labelling are very useful in image III.

Threats

- Institutions that control validity of data for labelling purposes are expensive to maintain and more administration is needed at the farmer and processing level
- The consumer's distance from the manufacturers means that retailing will play a crucial role when consumer demand for quality, food safety and environmentally friendly production is communicated down through food production's many chains

(General literature sources: Cuhls 2006; Thoni et al 2009; Borch et al 2008)

5.4 Transportation networks

Physical accessibility to markets is a prerequisite for selling products. Goods can either be transported by road, railroad, ship or airplane. Either way the investment in infrastructure is heavy and in the most developed areas of EU it has been an ongoing process for centuries.

Strengths

- Efficient transportation networks (e.g. by means of highways, cargo trains, harbours and airports) is necessary to gain access to global markets and maintain competitiveness *(Target 3)*
- Multifunctionality based on tourism need some level of network for transportation of people *(Target 4)*

Weaknesses

- Improvement of transportation networks has shown to increase transportation and thus energy use. This dynamic is often referred to as Jevons paradox: when a service is made more easy accessible the consumption of this service tend to increase*(Target 6)*

Applicability related to images

In image I and to some extend image II access to global markets are important and development of interregional transportations networks (e.g. highways, harbours and airports) can be necessary for less developed areas of EU. In image III agricultural production mainly serves local markets, as has been the case for centuries, and sufficient transportation networks are therefore expected to be in place in most areas.

Threats:

- A potential rise in oil prices will both make it more expensive to transport goods and to build and maintain transportation networks. Investments in transportation networks can turn out to be a bad investment.

5.5 Bioenergy and biomaterials technologies

This group of technologies is concerned with processing of biomass into energy, materials and chemicals; examples are biogas fermentation (producing energy and fertilizer), 1. and 2. generation bioethanol fermentation (transportation fuel) and the integrated biorefinery (processing facility that extracts carbohydrates, oils, lignin, and other materials from biomass and converts them into multiple products). Already today, corn wet and dry mills and pulp and paper mills are examples of biorefinery facilities that produce some combination of food, feed, power and industrial and consumer products. Waste products can be turned into biogas along with urban waste. Today a number of biorefinery processes are being developed and tested in pilot plants, e.g. Whole Crop Biorefinereies (WCBR), Oleochemical Biorefineries (based on oil crops), Lignocellulosic Feedstock Biorefinereies (LCFBR), Green Biorefineries (GBR) based on green and wet biomass such as grass and clover and Marine Biorefinereies (MBR) based on aquatic biomass.

Strengths

- Bioenergy offers a unique form of renewable energy since it is the only alternative to liquid and solid fossil fuels. 1. and 2. generation bioethanol offers a liquid fuel that more or less can be distributed in existing energy infrastructure and be used in existing gasoline engines. *(Target 6)*
- Production of biogas from agricultural residues and energy and nitrogen fixating crops offers a win-win situation for low-input and organic agriculture since it can both produce energy (methane) and a valuable fertilizer from the digestate. Biogas can either be used in a CHP-unit (Combined heat and power), with the right infrastructure it can be used as natural gas is used to day or it can be used as a transportation fuel. *(Target 1, 4, 6)*
- Biomaterials offers the possibility of substituting nonrenewable fossil materials with biobased ones *(Target 6)*

Weakness

- Biomass production and processing into fuels, materials and chemicals are in general much more energy and labor intensive than using fossil input, and it does not pose a real alternative to fossil fuels as a main power source for an industrial economy
- The natural variety of the different components in the biomass makes extraction complicated and expensive in terms of energy and money
- The challenges related to increase of land used for high-input agriculture for non-food purposes

- Uncertainty about the connection between removal of biomass and soil fertility to clarify critical limits for content of organic material in the soil

Applicability related to images

This set of technologies is relevant for all images. But in image I and II centralized large scale bioenergy and refining is more suitable whereas in image III farm and village scale bioenergy and refineries are more suitable.

Threats

- Bioenergy is unable to compete with fossil fuel on equal terms
- High uncertainty to whether more sophisticated 2nd generation bio-refineries will be cost-effective
- Public hesitation about using farm land for non-food production

(General literature sources: Borch et al 2008; Jong et al 2010; Shütter and Peters 2010; Bagger et al 2004; Giampietro and Mayumi 2009)

6 Policy measures for promotion of technologies

In this chapter policy options for promoting innovation within agricultural technologies in general and policies for supporting spreading and implementation of the specific examples of technologies addressed above are discussed.

Interdisciplinary research: Agricultural research take place in various disciplines and new technological developments mainly occur at the borderlines of agricultural research. Therefore interdisciplinary research is needed and agriculture should look much more to what is happening elsewhere and that it should open up to other disciplines (Cuhls 2006).

Measure: Research programs that support interdisciplinary projects with rural development and agriculture in focus. Some of these programs needs to target identified specific regional challenges since these vary considerably across EU regions.

Education: A successful diffusion and application of many of technologies require education and training of the farmers and other involved parties. This concerns "good agricultural management" as well as the use of knowledge systems offered by IT systems, and high tech systems such as robotics and precision farming.

Public intervention has an important catalytic role in stimulating and supporting the education and training provided (e.g. through subsidizing the costs of training). Successful initiatives of this kind in Europe have been either formulated or modified by regional and local level institutions, thereby helping to achieve a good fit with local needs and circumstances (North and Smallbone 2006; Vedmand and Odgaard 2009).

Measure: Supplementary training programs formulated by regional level institutions - especially in the new member states

Technology transfer: Many of the technologies from table 1 are already functioning in some regions of EU, especially in north vest Europe. If these technologies were introduced in other parts of Europe (e.g. our case region Rodophs) a significant increase in yield can be expected, without claiming additional land.

Measure: Support demonstration and pilot projects involving supply and demand side. Establishment or strengthening of larger regional knowledge centers, extension and consultative service

Enlargement of ITC infrastructure: In any case sharing of knowledge will be a cornerstone for competitiveness of European agriculture, and access to the Internet in peripheral rural areas can be a valuable help to do that. But as emphasized by North and Smallbone (2006) ICT is no "easy fix" and cannot stand alone without education as discussed above.

Measure: Support extension of broadband access in remote rural areas

The phase model. Support in order to promote and mature new technologies (e.g. biofuels, precision farming etc.) could be designed according to the so called "phasemodel" (Jensen 2004) that builds on the Danish experience with wind turbine technology. The efficiency of the phase model depends on the technology and national marked and industry structure. However in the following we will focus on some general conclusions.

Development of technologies and public support to reduce costs can be divided in the following faces:

1. *Pioneer phase* where a prototype with a reliable future potential is developed: Support mainly to fundamental research and demonstration facilities and stimulation of communication between research environments.

2. *Introduction phase* where the developed product are introduced to the market: Support to set-up industrial standards along with investments in both industrial and public R&D in order to stimulate both process and product innovation. Communication between industry, government and research institutions is extremely important in order to exchange (tacit) knowledge.

3. *Market phase* where the technology is reliable and gets established in the market: Low public R&D in the form of market stimulation (Market-pull) in order to stimulate industrial R&D on product development. Communication of codified knowledge is essential in order to stimulate recombination of knowledge in order to create new knowledge and ideas.

4. *Competition phase* where the product is mature: The technology is mature and its products can compete on equal market conditions with conventional technologies and therefore now further public support is necessary.

In this approach to public support to development of new technologies is focused on the amount of technological knowledge a specific knowledge is able to generate and how it is determined by the relationship between the amount of resources devoted to R&D and learning activities, and the ability to use external technological information through communication in the innovation system

Specific policy measures for promotion of examples of technologies: Table 2 summarizes general policy options for development and promotion of new technologies and specific policies that can counter the threats for the technologies describes in chapter 5 of this report. The majority of the policies are economic *incentives* (e.g. subsidies and taxes), *command and control* (e.g. IPPC-directive and BAT-requirements (Best Available

Technology)), *soft measures* (e.g. information campaigns, education) or *financial support* for research. In some cases establishment of official institutions is also considered as a policy option.

Table 2: Technologies and corresponding targets and policy measures

Targets	Technology	Policy measures
1-6	General	• Support to interdisciplinary research to benefit from results in adjacent disciplines • Supplementary training programs formulated by regional level institutions - especially in the new member states • Technology transfer to less developed regions and establishment of knowledge centres and demonstration and pilot projects involving supply and demand side • Support extension of broadband access in remote rural areas • The phase model
1, 2, 6	Crop rotation, cultivation and soil preparation technology	Policies should aim at minimizing the loss of nutrients due to denitrification and methane emission by improving agricultural practices and spreading good practices throughout EU. Policies could include: • Taxes on fertilizers thus giving an economic incentive to make the most out of the fertilizers • Lowering the amount of fertilizers allowed per area • Financial support for research in new growing systems such as reduced or no tillaging and crop rotations with catch crops and N-fixating crops • Education of farm labor and support for public research could help develop and implement new ways of farming
1, 2, 3	Precision Farming	• Financial support for development of the technology including, e.g. research programs on development of algorithms analyzing growth conditions needs and precise • Subsidies and BAT-requirements can become relevant for specific processes
1, 2, 3, 6	Genetic modification of crops (GM)	Challenges concerning GMO's are primarily concerning public and political hesitation. It is necessary to take a policy decision on the use of GMOs including both an approval procedure and labelling that reflects the public's very broad impression of risks. The technology is still at a somewhat early stage, and therefore research programs on GM technology and risk must be upgraded, if EU decides to stake on the technology. The Danish Synthesis report suggests two models for authorization of GMOs (Danish Ministry of Food, Agriculture and Fisheries 2009): 1. Authorization could be based on an overall assessment of the genetically modified product under authorization review with regard to expected benefits and risks. Thus, the greater the benefits, the greater the acceptance of potential disadvantages. 2. Apart from requiring that the genetically modified product under authorization review represents the same low level existing before it is

		authorized, it must also meet a requirement that it represents substantial benefits.
3	DNA marker assisted breeding of animals	• International coordination will enhance the results
1, 3, 6	In vitro meat	• Challenges are to a large extend concerning public and political hesitation.
3, 4, 5	Internet access	Subsidies development of ICT and transport infrastructure in less developed areas.
1, 3, 5	Traceability technologies – e.g. RFID-tags	Establishment of official institutions that can control validity of data is a key issue because there is likely to be an economic incitement for cheating with data concerning origins in time and space of food and feed. Institutions also need to organize information in a way that prevents consumers from being overloaded with information. This is typically done by labelling.
3, 4	Transportation networks	Financial support to development of infrastructure in less developed rural areas of EU
1, 4, 6	Bioenergy and biomaterials technologies	There is still significant uncertainties and disagreement about whether bioenergy and biomaterials are capable of replacing a significant part of fossil inputs in an industrialized/developed economy. So the consequences of a *biobased* economy should be more thorough investigated, before setting more ambitious targets. But given that biomass will be important as fuel and materials in the future continues development and implementation of relevant technologies could for example be supported by economic incentives (e.g. subsidies and taxes) and financial support for research. • Support research in negative tradeoffs related to large scale substitution of fossil based energy and materials with biobased • The "phasemodel" (see above) • Continues development and implementation of relevant technologies could for example be supported by economic incentives (e.g. subsidies and taxes) and financial support for research

7 Discussion

Policy measures corresponding to different technologies made in the coming decade will greatly influence the future development of EU agriculture beyond 2020 as the implementation of changes is very slow. With this in mind, it is even more important that the 2020-images are embraced by the policy makers. This is a very difficult task as recommendations from any study are heavily influenced by the assumptions (often not formulated) about future development: is it a future of strong economic growth with ever increasing global integration of markets and exchange of products, or is it a future with severe energy constraints with little energy available to support global production chains and development of new technologies? Both views are legitimate but the recommended policies are likely to be directly opposing, e.g., “Biofuels and –materials can replace oil in an industrialized knowledge based economy” (Hardy 2002, Farrell et al 2006) and “biofuels cannot replace oil as a main energy source, and long-term agricultural productivity is likely to be undermined if we try” (Giampietro and Mayumi 2009). Such contradicting conclusions arise from the complex nature of the examined area - agriculture world marked. Complex systems by their nature involve deep uncertainties and a plurality of legitimate perspectives (Funtowicz 1999).

The AG2020 targets, the image narratives and the technology imperatives has been the main guiding parameters for our choice of technologies included in this report. Below we will discuss to which extend it is likely that the targets can be achieved by means of these technologies in each of the three images. However, in assessing the usefulness of different technologies, it is problematic that AG2020 do not include an images with severe global energy constraints which, as discussed in chapter 2, are likely to have a dramatic impact on the organization of the agri-food sector and the society as a whole within the next decade. The general assumption for all three images and the AG2020 project as a whole is that there will be enough energy available and that technologies based on other kinds of renewable energy can substitute fossil oil when needed.

To which extend can technologies fulfil the AG2020 targets in Image I?

Image I is the most technology intensive image; risks associated with technologies are broadly accepted and the technologies are developed as far and fast as possible. Here agriculture is seen as a high input and high output business. This makes this image vulnerable to price fluctuation on necessary inputs such as commercial fertilisers, energy for farm operation and for transportation, which would all be expected to follow the price pattern on the global oil market. And even though many of the technologies (e.g. centralized biorefineries, biotechnology and GMO, interregional transportation networks etc.) can rightfully be expected to increase labour efficiency and productivity, the centralized organization of the agri-food sector and high integration into global markets are energy intensive solutions. This constitutes a sort of paradox since in trying to become less depending of fossil fuels, the strategy applied will presumably cause an overall higher energy use. Achieving the biobased economy blending targets *(target 6)* is supposedly possible. However, it may turn out to be very problematic – if not impossible - to significantly go beyond the moderate target due to the low output:input ratio of biobased energy and materials, compared to the fossil fuels which is at the moment fuelling the industrial economies with energy and materials. Thus, in this image there must be focus on energy efficient technologies and the role of agriculture in biofuel production. Alternatively bioenergy can be imported from e.g. Latin America. Whether import of biofuels from Latin America is sustainable depends on technology development and Latin American biofuel policy (BioTop, 2010).

Beside the energy aspect, Image I faces other central dilemmas. It is problematic to combine in the same area high input competitive agriculture *(target 3)*, conservation of biodiversity *(target 2)* and a broader rural development since less labour is needed in agriculture and since high input agriculture in general offers a rather uniform landscape, with fewer opportunities to develop multifunctionality *(target 4)*. So in order to fulfil these three targets a balance should be established, by for example intensifying production in some areas in order to make diverse landscapes and create nature reserves in others. Improvements and advances in cultivation and soil preparation technologies, precision farming technologies and biotechnology can presumably all help to increase yields in the intensive managed areas. But bearing in mind that EU is already a net importer of food (Johansson 2010), allocation of arable land to energy crops or nature reserves implies the risk of increasing dependence on imported food.

The interregional and global distribution networks needed to both supply the agri-food sector with industrial inputs, and to process and distribute the agricultural outputs, would risk becoming useless in case of a steep increase in transportation cost or a temporary shortage of transportation fuels. High input agriculture with a centralized organization of processing and export to global market is also expected to increase energy use, which put even more emphasis on developing technologies for reducing GHG emissions *(target 1)* in connection with agricultural production; different biogas technologies seems to be an important contribution.

Finally, regarding traceability of food and feed *(target 5)* it is fair to assume that fulfilling this target will be increasingly difficult with increasing integration into global markets. ICT infrastructure and technologies such as RFID-tags will make the task easier, but it cannot substitute the need to have official institutions that control and validate data. And with longer production chains more administration and control is needed in every link of the chain.

To which extend can technologies fulfil the AG2020 targets in Image II?

In Image II an industrial biobased economy is pursued with focus on development of industrial scale technology intensive solutions. The organization of the agri-food sector is similar to that of Image I with industrial high-input agriculture and centralized processing and access to global market; however to a lesser extent. Image II, therefore, faces the same set of dilemmas as discussed in image I. This also holds true regarding energy price spikes and shortages because, as discussed earlier, biobased energy may not be able to replace fossil fuels as a *main* energy source for an industrialized economy. And given that the blending target for transportation fuels is only 10%, the economy would still be relying almost 90% on fossil fuels for liquid transportation fuels, then the economy as a whole would still be very vulnerable to global energy price spikes and shortages.

The major difference between image I and Image II is the focus on the environment in Image II, thus environmental friendly and GHG-efficient technologies will be chosen before output efficiency. Although the image is positive towards GMO technologies, they will not deliberately be released in the nature before they have proven to be environmental benign, thus demanding a tough and more standardized approval procedure than what exists today.

To which extend can technologies fulfil the AG2020 targets in Image III?

Image III differs significantly from the other two images concerning the organization of the agri-food sector. Here, agricultural production manly serves local markets, and the production is in general more low-input and to greater extend based on organic farming principles. Therefore, this image is less vulnerable to fluctuations in inputs such as commercial fertilizers and to some extend liquid fuels, since less transportation of agricultural products and inputs is needed. But on-farm operations will presumably still rely on fossil fuel, so in case of a severe oil crisis the strategy of Image III is also likely to be challenged. However the starting point in Image III does give a better opportunity to continue food and energy production in case of an oil crisis since more local distribution networks are in place and since the agricultural production systems and the soil itself are less accustomed to a high degree of input of advanced technologies and commercial fertilizers.

Apart from risks associated with energy constraints, the strategy of Image III is likely to cause other opportunities but also dilemmas concerning fulfilling the targets. Increasing use of low-input and organic farming principles would, other things being equal make it easier to preserve biodiversity and to support multifunctionality, due to a more diverse landscape and more local business opportunities in connection with processing and distribution of food *(target 2 and 4)*. And the local production chains would make it easier to trace food and feed *(target 5)*. On the other hand, technologies to increase yields and quality are needed to compete on global markets *(target 3)*, since producers outside EU in the short run can benefit from more energy intensive production methods. However, if the local population prefers local quality products, as they do in image III, then local producers would have an absolute competitive advantage, and they would not need to compete on global markets. The down side is that consumers must be accustomed to a narrower and season dependent selection of produce. There is the risk that technology capable of reducing N_2O and methane emissions, such as advanced livestock stables would be applied to lesser extend in crop and animal production which could make it difficult to fulfil the GHG target (*target 1*).

8. Conclusion

This report has discussed agricultural related technologies that are likely to support compliances with the AG2020 targets in the three images and what kind of policy measures that can be applied to support development and diffusion of the technologies.

In our view, Image III is the least energy intensive image, and it is therefore also the image that would constitute the best starting point for transforming the agri-food sector from being an energy consuming sector into an energy producing sector. Image I and II both involve more centralized and regional specialized production methods and increased integration into global product chains which presumably would imply increased energy consumption. Likewise, image I and II will presumably involve severe difficulties with fulfilling targets concerning GHG-emission reduction, biodiversity preservation, multifunctionality, and food and feed traceability and at the same time fulfilling targets on competitiveness and on biobased economy, since the proposed technologies and measures from these two groups of targets to some extend will counteract each others.

None of the technologies discussed are easy fix's to fulfil the targets. For instance, the idea of substituting our dependence of fossil input partly supplied from political unstable regions with homegrown renewable materials is very appealing. However, there is a growing concern that it will simply not be possible to produce the needed amounts of biomass to supply an industrial economy.

At the same time it is unavoidable that biomass will be an increasingly important source of energy and materials in a future with diminishing oil, gas and coal production. Hereby is also said that investment in biobased energy and materials will be a key driver to fulfil the AG2020 targets. The future development within global energy markets and within other renewable energy sources will show whether enough energy can be supplied to maintain the industrial economy.

We recommend that more research will consider to which extend biofuels and materials can supply an economy, and how a society that is more or less based and powered on biomaterials would look like. How many of us would have to work in the primary sector with supplying the rest of the society with biobased energy and material? And with what kind of technological and economic feedback would the rest of the economy be able to supply the farms and industries.

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